

beginning in the Pacific Ocean southeast of Japan, where the drift turns from a westerly to a northerly course, and flows to the north and then to the northeast to the Gulf of Alaska, where it divides into two branches, one continuing as a warm current through the Aleutian Islands and the other turning to the south to become the somewhat indefinite California Current. The California Current flows southward at some little distance from the western coast of the United States, and the water which has left the Tropics as the Japan Current is replaced by the California Current, so that the tropical ocean may not be losing water continually to the Alaskan region without adequate return to keep the amount of water in each place constant.

Near the coast of California the water is decidedly colder than it is in the open ocean, but as this coast strip has a lower temperature in the vicinity of Cape Mendocino than it has either north or south of this point, the cold strip must be the result of an upwelling of cold water from the depths of the ocean and not the result of an ocean current. The reports of vessels show that the movement of the surface of the ocean near the shore is irregular, but that farther out there is a general movement toward the Equator.

The facts of observation show that the Japan Current does not come within 900 miles of any part of California, and consequently can have little influence upon the climate of the State. But it is a fact that the climate of California is much milder than that of the greater part of the United States. The explanation is to be found in the great ocean which lies to the west and in the fact that the winds prevailing blow from this ocean to the land. The temperature of the ocean water varies little from 55° during the year; in some places it is more and in some places less, but it is everywhere relatively constant through the year. The air lying over this great body of water has nearly the same temperature as the water, but were it not for the westerly winds, the climate of California would be little influenced by the ocean.

Compared with the land areas in the same latitudes the oceans have very mild climates. Everywhere the oceans are warm in winter and cool in summer because water is, of all the substances we know, among the most difficult to heat and to cool. The result is that the temperatures of the ocean and the air over the ocean remain nearly constant. But land is about twice as easy to heat and twice as easy to cool as is water, so that the land and the air over it have warm summers and cold winters, warm days and cool nights.

The fact that the winds blow from the ocean to the land is of the greatest importance to California. It is these winds which bring the mild ocean air over the land and give to this State a climate cooler in summer and warmer in winter than that of other parts of the country. The Pacific Ocean and the westerly winds from the ocean can and do produce all the beneficial results that have been claimed for the Japan Current, and it is to these two features of nature that we owe our mild climate. Whatever effect the Japan Current may have upon the Gulf of Alaska and upon the climate of the Territory of Alaska, and there is no doubt that this effect is very important, the State of California owes nothing to this warm current. The cool summers in the coast region of the State and the fogs which occur during that season are, in part, due to the presence of the cold water off the coast, and that part of the North Pacific drift known as the California Current may be one of the reasons for the existence of this cold water, although a far more important reason seems to be the upwelling of the cold water from the ocean depths. It is the Pacific Ocean and the westerly winds to which we must look for the chief reasons why the climate of the Golden State is favored above that of other lands.

MILD WINTER OF 1913-14.

AN UNUSUAL PHENOMENON.

Dr. Louis Bell writes from Boston, U. S. A., to describe an unusual meteorological phenomenon observed there last month. On January 13, which was the coldest day known in Boston for many years, the thermometer not ranging above 0° F. for a period of 30 hours extending through the entire day, Dr. Bell, upon entering a large train shed some 75 feet high and of a very extensive area, found that snow was steadily falling, produced by the congelation of the steam from the numerous locomotives. The interesting point was that the snow had aggregated into flakes of fair size, not distinctly crystalline, but still flakes, in spite of the short distance of the possible fall. The thermometer was then about 5° F. below zero, and in the evening at a similar temperature the whole interior of the train shed was still white with this deposit of snow.

The general phenomenon, of course, has been many times recorded, but is very rarely seen, particularly on so large a scale and for so long a time.

WINTER OF 1913-14.

The exceptionally mild character of the present winter is being maintained until its close, and for a persistent continuance of warm days in January and February it surpasses all previous records. At Greenwich the thermometer in the screen was above 50° for 18 consecutive days from January 20 to February 15. Previous records since 1841 have no longer period than 11 days, in the months of January and February combined, with the thermometer continuously above 50°, and there are only four such periods—1846, January 21-31; 1849, January 16-26; 1856, February 6-16; and 1873, January 4-14. Besides these there are only three years, 1850, 1869, and 1877, with a consecutive period of 10 days in January and February with the temperature above 50°. The persistent continuance of the absence of frost is also very nearly a record. To February 24 there have been 30 consecutive days at Greenwich without frost in the screen, and the only years with a longer continuous period in January and February are 1867, with 37 days; 1872, with 43 days; and 1884, with 32 days. The maximum temperatures in the two months have seldom been surpassed. In many respects there is a resemblance between the weather this winter and that in 1899, when in February blizzards and snowstorms were severe on the other [American] side of the Atlantic, with tremendous windstorms in the open ocean, whilst on this side of the Atlantic the weather was exceptionally mild. It is to be hoped that this year we shall be spared the somewhat sharp frosts experienced in the spring of 1899. (Nature, London, Feb. 26, 1914, v. 92, p. 720-721.)

ON THE AMOUNT OF EVAPORATION.¹

By Y. HORIGUTI.

[Dated Kobe Meteorological Observatory, January, 1913.]

(1) In the present note I intend to give some results of my investigation of the evaporation of water in an atmosphere that is freely exposed to wind and sunshine.

This apparatus is a cylindrical copper vessel 20 centimeters in diameter and 10 centimeters deep. It is placed on the surface of ground that is covered with sod. Fresh water is poured in it to the depth of 2 centimeters and is freely exposed to sunshine and wind.

Every morning at 10 o'clock the amount of evaporation is determined by measuring the loss of water during the exposure. When rain or snow has fallen during the exposure the measured evaporation is corrected for the amount of precipitation shown by the rain gage placed near and at the same height with the atmometer.

First let us investigate theoretically the relation of evaporation and other meteorological elements.

(2) Suppose the case when the vaporizing water is not exposed to wind and direct sunshine, and is unhindered. Moreover, let us assume that the cylindrical vessel is so large that the effect of the surface tension at its periphery may be neglected.

Let the z -axis be vertical. Let p be the partial vapor pressure, then the upward force is $\frac{\partial p}{\partial z}$. The gravity and the resistance of air act downward.

¹ Revised reprint from Journal of the Met. Soc. of Japan, May, 1913, 32d year, No. 5, pp. 14-26.

Let ρ be the density of the water vapor at the partial pressure p and the absolute temperature T , but ρ' the density of the air at the partial pressure p' and the absolute temperature T .

Let u be the upward velocity of diffusion of aqueous vapor. Then the resistance is proportional to $\rho \rho' u$.

Then the equation of motion is

$$\rho \frac{d^2 z}{dt^2} = \frac{\partial p}{\partial z} + a \rho \rho' u \quad (1)$$

where t is time and a is a constant. The mechanism of evaporation is not known, but we assume that there is a layer of saturated vapor on the exposed surface of the water, and the vapor passes into the air by diffusion [without convection currents]. Therefore the process of evaporation may be treated as the diffusion of a gas through other gases. In such a case the acceleration of vapor may be neglected, and

$$\frac{\partial p}{\partial z} + a \rho \rho' u = 0 \quad (2)$$

Now $\rho u \times 1$ sq. cm. = the amount evaporated from a unit area in a unit time.

Put m = the evaporated mass of water in a unit time from a unit area, then

$$\rho u = m \quad (3)$$

Let δ' be the density of the air at the normal pressure P_0 and the normal temperature T_0 , then

$$\rho \rho' u = \frac{\delta' T_0 p'}{T P_0} m, \quad (4)$$

Therefore equation (2) becomes

$$\frac{\partial p}{\partial z} + a \frac{\delta' T_0 p'}{T P_0} m = 0, \quad (5)$$

since $p' = P - p$, where P is the total pressure, therefore

$$\frac{\partial p}{\partial z} = a \frac{\delta' T_0}{T P_0} (P - p) m = 0. \quad (5')$$

For simplicity, suppose that P and T are constant between $z=0$ and $z=h$; that the partial pressure of water vapor at $z=0$ is p_1 , or the maximum vapor pressure at the temperature T , and that at $z=h$ it is p_2 .

Put

$$a \frac{\delta' T_0}{T P_0} = \frac{1}{k} \quad (6)$$

then

$$k \frac{\partial p}{\partial z} + (P - p) m = 0 \quad (7)$$

or

$$m = -k \cdot \frac{1}{P - p} \cdot \frac{\partial p}{\partial z} \quad (7')$$

Integrating we get

$$m \int_0^h dz = -k \int_{p_1}^{p_2} \frac{1}{P - p} \cdot dp$$

$$mh = k \log \left(\frac{P - p_2}{P - p_1} \right) \quad (8)$$

$$m = \frac{k}{h} \log \left(1 + \frac{p_1 - p_2}{P - p_1} \right) \quad (8')$$

Now since p_1 and p_2 are small quantities compared with P , the above expression may be expanded, and we

may neglect the terms of the second and the higher orders.

Therefore we have

$$m \div \frac{k}{h} \cdot \frac{p_1 - p_2}{P} \quad (9)$$

Let w be the density of the water, dH be the depression of the water level in unit time.

Then wdH is the mass of the evaporated water in unit time from unit area, therefore

$$wdH \div \frac{1}{h} \cdot \frac{P_0 T}{a \delta' T_0 P} (p_1 - p_2).$$

Hence we obtain

$$dH = \alpha (p_1 - p_2) \quad (10)$$

where

$$\alpha = \frac{1}{h} \cdot \frac{T P_0}{a \delta' T_0 P} \cdot \frac{1}{w}.$$

From this we see that, as is well known, the [daily] amount of evaporation [or rate] is proportional to the deficiency of saturation.

(3) The discussion of the last paragraph refers to an ideal case; in an actual case it is necessary to take 24 hours for the time unit. Even the greatest amount of evaporation during 24 hours at Taihoku is less than 10 mm. on the average of the five years of observation (1900-1904).

The temperature, the total pressure, and the partial pressure are not constant as we assumed in the last paragraph, but are functions of the time.

The evaporation gage is a circular cylinder 20 centimeters in diameter instead of being of infinite dimension as was assumed in the ideal case; therefore in the actual case the boundary conditions and the effect of the meniscus must be taken into consideration.

Moreover, the evaporating surface is exposed to wind and sunshine. It is also very difficult to estimate the amount of evaporation in a rainy day, and in fact I often experienced so-called "negative evaporation."

Therefore the amount of evaporation observed by this method does not attain an accuracy of the order of 0.01 millimeter. Dr. Okada discussed the accuracy of evaporation observations in the Bulletin of the Central Meteorological Observatory (Tokyo), No. 1. His report indicates that from 2 to 61 years' observations are necessary to reduce the probable error of mean result of evaporation observations to 0.1 millimeter.

The foregoing considerations make it obvious that formula (10) does not hold in the practical case; therefore I devised the following empirical formula:

$$M = a + b(p_1 - p_2)$$

where M means the amount [per day or the rate] of evaporation expressed in millimeters of depression of the water level, and a and b are constants.

I shall proceed to find the values of a and b . I assume the total pressure P and the absolute temperature T to be constant through the year, because the fluctuation in a year does not have any considerable influence on the total amount of evaporation. The probable error of observed total is greater than the effect of this fluctuation.

(4) The constant b depends only on the deficiency of saturation. The terms $p_1 - p_2$ and a depend on all the remaining factors, viz, the effect of the inequality between the water temperature and the air temperature,

the effect of wind, sunshine, boundary conditions, etc. Therefore a is not a constant, but varies from month to month.

[Tables I to VIII omitted.]

TABLES IX AND X.—Computed values of b .

Station.	Latitude.	Longitude.	b
Taihoku.....	N. 25° 02'	E. 121° 31'	1.01
Naha.....	N. 26° 13'	E. 127° 41'	1.06
Nagasaki.....	N. 32° 44'	E. 129° 52'	0.89
Hamada.....	N. 34° 53'	E. 132° 05'	1.10
Tu.....	N. 34° 43'	E. 136° 31'	1.03
Tokyo.....	N. 35° 41'	E. 139° 45'	0.94
Hakodate.....	N. 41° 46'	E. 140° 44'	1.47
Sapporo.....	N. 43° 04'	E. 141° 21'	1.43

The constant b at the first six stations of Table IX-X are nearly equal, though these stations are far distant from each other, and the amounts of evaporation there observed are also very different. The general uniformity of b is natural, as I pointed out above, because b depends only on the deficiency of saturation.

But at Hakodate and Sapporo b differs from its value at the other stations. This is probably owing to the differences in the condition of evaporation. A glance at Tables VII and VIII [omitted], shows that the mean temperature in December, January, February, and March falls below the freezing point, and that even in other months the water in the atmometer will often freeze in such cold localities. Of course the values of b in the case of the vaporization of ice must be different from those for water. In fact the value of b for Hokkaido, which has a severe winter, is greater than that for the other stations having milder climate; the ratio is nearly as 1 to 1.4.

As already stated the constant a depends on the boundary conditions, wind velocity, etc.; but it seems that this constant depends chiefly on the temperature of the water, which my former calculation assumed to be equal to the air temperature. But in summer, daylight is much longer than nighttime, therefore the mean temperature of a water surface must be far higher than that of the surrounding air. The deficiency of saturation calculated by means of the air temperature and the vapor pressure is therefore a little smaller than the actual value. Hence a correction, arising from the difference in temperature of the air and the water in the atmometer, must be applied to the value of a calculated with the air temperature. Then a will vary from month to month and will show some relations to the duration of daylight.

The following table contains the computed monthly values of a , assuming b as a local constant without seasonal variations:

TABLE XI.—Monthly values of constant a .

Station.	Jan.	Feb.	Mar.	Apr.	May.	June.
Taihoku.....	0.42	0.73	0.77	0.88	0.62	0.93
Naha.....	-1.02	-0.49	0.17	0.29	0.27	0.85
Nagasaki.....	-1.39	-0.21	0.33	0.11	0.04	-0.85
Hamada.....	-0.53	-0.36	-0.16	-0.09	-0.36	-0.06
Tu.....	0.36	0.46	0.73	0.98	0.90	0.48
Tokyo.....	-0.07	0.03	0.30	0.28	0.17	-0.06
Station.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
Taihoku.....	0.58	0.50	0.49	0.53	0.28	0.41
Naha.....	0.25	-0.05	-0.48	-0.79	-0.56	-0.71
Nagasaki.....	0.28	-0.58	-0.94	-1.36	-0.56	-0.51
Hamada.....	-0.31	-0.46	-0.74	-1.16	-1.05	-1.05
Tu.....	0.76	0.18	0.53	-0.12	-0.27	-0.15
Tokyo.....	0.24	0.04	-0.42	-0.67	-0.37	-0.26

I analyzed the constant a by the method of harmonic analysis, and Table XII contains the values of the constants in the Fourier series:

TABLE XII.—Constants in harmonic series; analysis of a .

Station.	a_0	a_1	a_2	a_3	ϕ_1	ϕ_2	ϕ
Taihoku.....	0.00	0.11	0.05	0.07	351 50	111 48	254 4
Naha.....	-0.19	0.73	0.10	0.18	282 42	135 0	180
Nagasaki.....	-0.39	0.51	0.13	0.25	17 1	0 0	148 14
Hamada.....	-0.55	0.44	0.22	0.12	288 26	341 34	180
Tu.....	0.39	0.49	0.17	0.09	307 34	287 21	40 42
Tokyo.....	0.06	0.35	0.11	0.14	318 17	354 17	128 40

Here α is the amplitude, and ϕ is the phase angle. The amplitudes of the first term are greater than the amplitudes of the higher terms.

At Taihoku α_1 is less than α_0 ; at the other stations α_1 is greater than α_0 and the amplitudes of the higher terms. Its maximum values occur between March and June, and its minimum value between October and January. It seems to me that this fact may be accounted for by considering the duration of daylight.

The wind velocity must affect in some degree the rate of evaporation, but when we consider the mean monthly evaporation the wind effect is not conspicuous. I tried many times to find the relation between the wind velocity and the constant a , but the effort resulted in a failure.

(5) The above theoretical formula must represent the evaporation in shade, as in a thermometer screen, better than that at a place freely exposed to sunshine and precipitation. But the effect of the shelter on the rate of evaporation must be considered as one of the limiting conditions in the theoretical investigation. In general the air circulation through the shelter is not sufficiently free. Therefore the vapor pressure in the screen is not equal to that of the outside, especially when the atmometer is placed in it. Generally the vapor pressure inside the screen will be greater than that outside. Then the deficiency of saturation will depend on the velocity of the air circulation, and the velocity of the air circulation in the screen will be a function, $F(w)$, of the wind velocity. Hence the deficiency of saturation is a function of wind velocity. Therefore it is necessary to substitute $F(w)(p_1 - p_2)$ for $\alpha(p_1 - p_2)$ in formula (10).

In my computation I have used the results of observations made at the Hamada Meteorological Observatory, published in the Journal of Meteorological Society, Tokyo, August, 1911.

Now we shall find the functional form of $F(w)$. For a first approximation it seems to be sufficient to put it as the linear function of wind velocity. But the parabolic formula is more appropriate. We give below these two formulæ:

$$(A) \quad M = (p_1 - p_2)w$$

$$(B) \quad M = (p_1 - p_2) \{0.20\sqrt{w-3.4} + 0.27\}$$

where w is the wind velocity in meters per second.

When the wind velocity is less than 3.4 meters per second, the effect of the wind velocity on the amount of evaporation is not significant, and formula (B) becomes—

$$M = 0.27(p_1 - p_2).$$

The effect of wind velocity becomes more and more conspicuous as the velocity increases.

We give in Table XIV the differences between the calculated and observed values of the evaporation by these two formulæ.

In the means for the period 1904-1908, the calculated and observed values coincide pretty well.

(6) In his "Lehrbuch der Meteorologie" Prof. J. von Hann gives the following formula of the velocity of evaporation:

Dalton's formula

$$\frac{dv}{dz} = A(E - e),$$

where v is the amount of evaporation from water surface; z , time; E , maximum vapor pressure; e , actual vapor pressure; A , a constant.

Weilenmann and Stelling put the evaporation rate proportional to the wind velocity. On the other hand, De Heen, Shierbeck and Svenson assumed that the evaporation is proportional to the square root of the wind velocity. Moreover, they introduced $T: T_0$, or $(1 + \alpha t)$, into their evaporation formula.

Trabert puts

$$v = c(1 + \alpha t)(E - e)\sqrt{W},$$

where W is the wind velocity; c , the constant depending upon atmospheric pressure. When the mean pressure is B and the current pressure b , then c becomes

$$c \propto \frac{b}{B}.$$

Dalton's formula is identical with that which I have deduced theoretically in this note. For formula (10) is

$$dH = \alpha(p_1 - p_2).$$

But formula (10) and Dalton's formula do not represent the observed values.

TABLE XIV.—Differences between the observed evaporation, M , and the values calculated by formulæ (A) and (B).

	Jan.	Feb.	Mar.	• Apr.	May.	June.
1904.						
M	1.33	1.52	1.41	1.47	1.73	2.00
By (A).....	-0.09	0.13	0.15	0.30	0.38	0.26
By (B).....	0.03	0.14	0.11	0.26	0.29	0.15
1905.						
M	1.22	1.42	1.08	1.44	2.36	0.85
By (A).....	-0.03	-0.12	0.04	0.10	0.03	-0.11
By (B).....	-0.03	-0.06	0.00	0.05	-0.01	-0.12
1906.						
M	1.30	1.21	1.62	1.96	1.43	1.14
By (A).....	-0.23	-0.12	0.13	-0.19	0.26	0.17
By (B).....	-0.12	-0.03	0.20	0.16	0.23	0.23
1907.						
M	1.37	1.16	1.40	1.76	3.04	1.74
By (A).....	0.00	-0.10	0.21	0.25	-0.72	-0.04
By (B).....	0.03	-0.06	0.21	0.19	-0.29	-0.16
1908.						
M	1.48	1.21	1.51	1.43	2.13	1.69
By (A).....	-0.06	0.01	-0.03	0.24	0.09	-0.09
By (B).....	0.00	-0.01	0.03	0.19	0.01	0.21
Mean.						
M	1.34	1.30	1.40	1.61	2.14	1.48
By (A).....	-0.08	-0.04	0.10	0.17	0.01	0.04
By (B).....	-0.02	0.00	0.11	0.17	0.05	-0.02

TABLE XIV.—Differences between the observed evaporation, M , and the values calculated by formulæ (A) and (B)—Continued.

	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1904.						
M	1.83	2.45	1.66	1.40	2.25	1.97
By (A).....	-0.21	-0.21	-0.19	0.08	-0.04	-0.33
By (B).....	-0.35	-0.39	-0.30	0.02	0.03	-0.09
1905.						
M	1.81	1.31	2.13	1.70	1.92	1.47
By (A).....	-0.24	-0.12	0.23	0.05	0.03	0.00
By (B).....	-0.39	-0.27	0.10	-0.06	0.12	0.05
1906.						
M	1.33	1.57	1.19	1.52	1.54	1.77
By (A).....	0.23	0.05	-0.12	-0.12	-0.20	-0.47
By (B).....	0.46	0.14	-0.18	-0.18	-0.24	-0.16
1907.						
M	1.55	1.92	1.14	1.73	1.45	1.98
By (A).....	-0.01	-0.02	0.17	0.44	0.12	-0.43
By (B).....	0.05	0.03	-0.26	0.48	0.03	-0.15
1908.						
M	1.51	1.83	2.05	1.59	2.41	1.87
By (A).....	0.25	0.04	-0.27	-0.07	-0.20	-0.09
By (B).....	0.32	0.05	-0.36	-0.18	0.31	-0.12
Mean.						
M	1.61	1.83	1.63	1.59	1.91	1.81
By (A).....	0.00	-0.06	-0.04	0.08	-0.06	-0.26
By (B).....	0.00	-0.09	-0.20	0.02	-0.05	-0.09

Weilenmann and Stelling assume that M varies as W , and De Heen, Shierbeck and Svenson that M varies as \sqrt{W} . Their formulæ give us almost the same results in my calculations. My parabolic and linear formulæ hold good equally.

Therefore it may be concluded that evaporation in the shade may be fairly well represented by the formulæ of either Weilenmann, Stelling, De Heen, Shierbeck, Svenson, Trabert, or myself. But the evaporation in open air can not be represented by those formulæ.

It seems to me that there remains an ample field for further research.

EDITOR'S NOTE.—Various papers bearing on evaporation by Ferrel, Russell, Marvin, and others will be found in the MONTHLY WEATHER REVIEW and other publications of the United States Weather Bureau. An elaborate Annotated Bibliography of Evaporation, by G. J. Livingston, appeared in the MONTHLY WEATHER REVIEW from June, 1908, to June, 1909, and also reprinted.

A valuable summary of our knowledge of the laws of evaporation, for the period 1840 to 1892, will appear in the MONTHLY WEATHER REVIEW for March, 1914.

PREVENTION OF FOG.

By pouring oil on the disturbed ocean surface ship captains have often been able to greatly diminish the damage that would have otherwise resulted during severe storms. M. Georges Onofrio, director of the Fulvière Observatory, at Lyon, France, suggests that by pouring oil upon inland rivers and lakes we may check the evaporation and therefore the formation of fog. Experiments have been made on this subject by allowing a mass of tow moistened with a small quantity of oil to dip into a running stream of water. Thus an oily coating scarcely a millionth of an inch in thickness, spreads over the inland waters. If successful the 62 days of local fog should be replaced by 62 days of good weather annually. A mineral oil is the cheapest but animal and vegetable oils have some advantages. It is estimated that the total expense for the region that furnishes objectionable fogs in the neighborhood of Lyon will amount to about \$30 a day.